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Hygroscopicity-modified Passive Solar Design of Energy Saving Buildings

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Abstract. Hygro-thermal performance of building in terms of energy consumption for keeping the interiors within comfort conditions has been a prime area of research all over the world primarily because of the energy consumed by the mechanical systems. This paper explores the potential of developing a design rationale for building envelope in the case of air-conditioned or non-air-conditioned buildings in hot-humid regions, using passive solar method based on hygro-thermal performance. An appropriate quantity for assessment of transient- hygroscopic nature of envelope material is proposed. Test results for some typical envelope materials are also reported**.** In the case of modern tall buildings, the hygroscopic nature of external component of wall can be exploited as a passive solar technique. It may be concluded that east and west walls with an external cover of hygroscopic materials will result in significant reduction in heat gain due to solar radiation.

Keywords: building envelope , transient-hygroscopic nature, passive solar method

1. Introduction

The cooling of buildings by using passive methods has evoked great interest in the context of need to minimize energy consumption by buildings. Achieving thermal comfort with minimum energy consumption is possible by designing building envelope considering its passive solar performance. Hygro-thermal performance of building envelope in terms of its potential for being used as a passive solar method in reducing heat gain has been a prime area of research all over the world. Although evaporative cooling as a passive solar technique is well-studied for its application in hot-dry areas, hygroscopic nature of building envelope materials needs more studies to develop design rationale for design of building envelope in hot-humid regions, for their potential of being used as passive solar method .

2. Passive Solar Design

The underlying principle of passive cooling is to prevent heat from (or at least reduce heat flux) entering the building, or remove heat once it has entered. The various concepts discussed in literature are ventilation cooling, evaporative cooling, nocturnal radiation cooling, desiccant cooling and earth coupling [1]. The applicability of these concepts depends greatly upon the climatic conditions prevailing in a particular place. Thermo physical properties of decisive nature are thermal resistance (R) and heat capacity (Q) of the building envelope.

Heat capacity (Q) of a wall or roof here refers to the amount of heat required to elevate temperature of unit volume of building envelope element, or unit area of the surface, by one degree. A high structural heat capacity is effective in moderating the internal responses to fluctuations of external surface temperature. The

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required magnitude of heat capacity corresponding to a given internal temperature is therefore closely related to the surface temperature rise due to solar radiation than to the maximum value of outdoor temperature.

Heavy external wall is a traditional technological option based on passive solar principle in many geographic regions, especially the hot-humid regions of the world. Technique of increasing heat capacity, not necessarily increased mass, is still a topic of interest due to ever increasing energy efficiency concerns owing to the possible energy conservation and associated favorable environmental impacts.

Thermal Resistance or the ‘wall U value’ as derived from simple steady state considerations does not truly reflect the dynamic thermal performance nor does represent a reliable energy conservation indicator for walls. It is established that the high thermal capacity of certain traditional building materials (like wood, earth, certain stone types etc.) can store much of the heat absorbed during the day keeping the interiors of dwelling constructed from earth relatively cool. The specific heat capacity of such materials is considered to be a key factor in its ability to moderate temperature swings in buildings. However adobe materials have relatively high thermal conductivity. Studies directed towards other factors that might explain its excellent behavior as a heat moderator revealed the significance of hygroscopic behavior of the wall material and its influence in the relative humidity of indoor air. In real situation a hygroscopic material on the building envelope will experience frequent wetting and drying. This is due to seasonal precipitation on large scale and everyday depending on the diurnal variation of air-temperature and RH. (Response of building material to the diurnal wetting and drying is mentioned in ancient and traditional literature on Indian architecture as “breathability” of a building.)

The conventional estimation of heat capacity and thermal resistance do not consider the thermal effect of hygroscopic sorption characteristics of envelope materials, because, the envelope materials were presumed to be waterproof and non- absorbing, for obvious functional reasons. So far, evaporative cooling as a passive solar technique is considered inappropriate in hot-humid regions citing high humidity as a problem, and has resulted probably in missing a closer look at the diurnal variations of temperature and RH [2]. That the highest values of temperature and RH do not happen at the same time instance, can be a potential idea for using hygroscopic nature for passive cooling techniques. And that it is the hygroscopic nature of external wall that is used and not that of the internal surfaces, rules out the fear related to high RH.

2.1. The Hygroscopic action

In high humidity areas, diurnal variation of air temperature and RH can cause condensation on envelope surface if it is kept at a temperature lower than the dew-point. If envelope material is hygroscopic (as it is always in the case of traditional building materials), it absorbs moisture from the atmosphere, the sorption being dependent on the relative humidity. This absorbed vapour condenses in the surface-pores of the envelope material when the temperature in pores falls below dew point. During heating due to solar radiation, certain amount of heat will be used as latent heat of evaporation of the absorbed moisture. This natural phenomenon can be suitably manipulated to reduce heat gain by building envelope. In order to do this, assessment of hygroscopic properties of envelope materials in transient conditions are to be assessed. Existing ASTM protocols for assessing hygroscopic sorption and the recent recommendations of NORDTEST (2005) do not reflect these properties adequately. Our effort is to develop suitable parameters to quantify hygroscopic behaviour of building envelope materials in transient conditions and fill this gap.

(Quantification of hygroscopic sorption moisture is also important in prediction of moisture- induced decay of building materials.)

Amount of water vapour absorbed depends on RH, duration of exposure, temperature and hygroscopic sorption characteristics of the envelope materials [3].

Moisture adsorbed by the envelope and corresponding latent heat removed during drying can be estimated the following way :

$$Q_m = K.\ f(T)\ f(H)\ f(t) \qquad (1)$$

Q_m = Moisture adsorbed

T= Temperature ; H= Relative Humidity

t= time duration of adsorption

K = Constant representing hygroscopic nature of the material

$$Q_h = h_d\,(w_1 - w_2) \times h_{fg,1} \quad (2)$$

Q_h = Latent heat removed,

h_d = Rate of desorption,

w_1 and w_2 = humidity ratios

$h_{fg,1}$ = Latent heat of vaporisation of water at temperature t_1

This model can be used only if the hygroscopic sorption and desorption behaviour of the material is known.

ASTM protocol C 1498-04a (ASTM, 2001) refers to the creation of sorption isotherms and establishing relation between RH and equilibrium moisture content at a specified temperature. It was found that this is insufficient to assess the hygroscopic behavior of building envelope materials since the effect of changing RH conditions are not taken into account by the protocol.

Straube reported comparison of sorption isotherms of some building materials as per ASTM protocol, which measured the saturation moisture content at various RH exposures irrespective of the time factor of sorption [4,5]. NORDTEST protocol [6] determines the Moisture Buffer Value (MBV) as follows: The standard specimen, when exposed to climate chamber set to maximum value of RH 75% for 8 hours, absorbs water vapour, and when subsequently exposed in the chamber set to a minimum value of RH= 33% for 16 hours releases water vapour. The cycles of absorption and desorption are repeated till the rates stabilize. Average of absorption and desorption rates for the maximum and minimum RH values of 75% and 33% are taken as measures of MBV.

Moisture Buffer Values (g/m^2.%RH) obtained after stable cycles [7] :

Cement Plaster (75% RH)	28.2 g/m^2
Cement Plaster (85% RH)	60.2 g/ m^2
Gypsum Plaster (75% RH)	45.8 g/ m^2

Considering the transient RH conditions, this measure is not realistic and cannot be used to estimate the overall hygroscopic behavior. A quantity that accounts for the amount of sorption/desorption water vapor per unit area per change in %RH will be a useful measure in estimating hygrothermal behaviour Therefore we proposed a new procedure which incorporates the transient behaviour.

2.2. The Experiment

In our experiment, we exposed the specimens to varying diurnal RH conditions in real time and measured the absorption and desorption after stabilization. The sample surface area is an important parameter. Therefore to control it, only the top surface is exposed and all other surfaces are covered by non-absorbing tape. As per ASTM protocol for plotting sorption isotherm, a balance that can weigh 1 mg had to be used. Such balances have a maximum capacity of only 200-300 gm with accuracy. Therefore samples weighing less than the maximum capacity were used. In the actual application of results, the area of building envelope was more significant and the volume of envelope material can be ignored as the saturation probability is negligible in the critical heating periods. This suggested exposing of only one surface of the sample and covering of other surfaces with non-absorbing materials. Weather-station and data-logger were used to measure RH and Temperature continuously. Samples were kept close to the external wall (on the window sill) to simulate the external envelope behaviour. Sample results are shown in Fig.1. RH was noted by weather-station data-logger at regular intervals and weight of samples with controlled exposure areas were measured using an electronic balance.

2.3. Discussion

Experimentally determined sorption rates, multiplied by appropriate RH range, time of exposure and area of external envelope is a good estimate of total quantity of moisture that takes part in the dynamic hygroscopic response of building exposed to transient-periodic conditions. Latent heat corresponding to evaporation of this quantity of moisture implies the reduction in heat gain that the envelope could achieve due to hygroscopicity.

Similar tests done on other envelope materials also gave useful results. Plywood of two different densities (used for interior paneling) and cement mortar of proportion 1:4 (used for plastering exteriors) gave the consistent sorption values (Table 1)

Walls made of hygroscopic materials are very common in traditional buildings in hot-humid regions of India. With a fixed height of the external wall, total reduction in heat gain due to hygroscopic nature of wall material is proportional to the length of wall or the perimeter of the building. Design guidelines can thus be linked to the building perimeter.

In the case of modern tall buildings too, the surface area of wall is relatively more compared to the roof area and the hygroscopic nature of external component of wall can be exploited as a passive solar technique. East and west walls with an external cover of hygroscopic materials will result in significant reduction in heat gain due to solar radiation. Detailing of hygroscopic envelopes incorporating operational flexibility and aesthetic requirements is a promising future direction of work.

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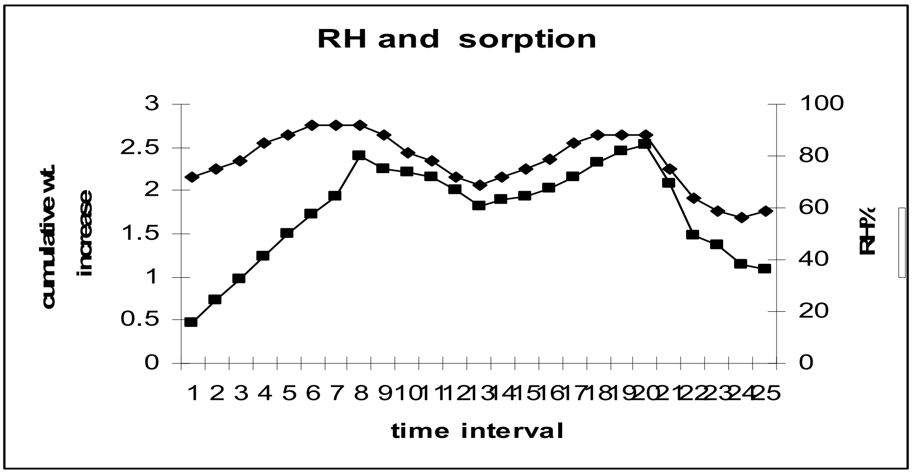

Fig. 1 Sorption by brick (black square) under diurnal RH variation (black diamond) measured for 2hr time interval

Note: The above values are for a sample which weighed 162.3825 gm, with surface area = 99.46cm^2

Mean absorption = 4.45 g/sq.m/hour/% increase in RH

Mean desorption = 5.26 g/sq.m/hour/%decrease in RH

Table 1 : Sorption characteristics of building envelope materials

Material	Sorption	Desorption
Brick	4.45	5.26
Plywood (Density 0.6g/cc)	5.82	6.83
Plywood (Density 0.8g/cc)	5.10	6.31
Cement Mortar CM 1:4	6.73	8.24

Note: Sorption in g/m^2.hour.% increase in RH ; Desorption in g/m^2.hour.% decrease in RH